ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 16 (2016) 717–723

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

The influence of severe plastic deformation processes on electrical conductivity of commercially pure aluminium and 5483 aluminium alloy

Marta Lipińska[*], *Piotr Bazarnik*, *Małgorzata Lewandowska*

Faculty of Materials Science and Engineering, Warsaw University of Technology, Wołoska 141, 02-507 Warsaw, Poland

ARTICLE INFO

Article history:
Received 8 December 2015
Accepted 30 April 2016
Available online

Keywords:
Severe plastic deformation
Electrical conductivity
Aluminium
Microhardness

ABSTRACT

Commercially pure aluminium 1050 and aluminium alloy 5483 were processed by Severe Plastic Deformation processes, i.e. Equal Channel Angular Pressing and Hydrostatic Extrusion in various configurations. Electrical conductivity and Vicker's microhardness were measured for as-received and deformed materials. Microstructure was investigated using Focused Ion Beam Microscopy and Transmission Electron Microscopy for coarse grained and deformed materials, respectively. The Severe Plastic Deformation processes bring about a significant grain size reduction, which was accompanied by an increase in microhardness. The results have shown that the grain size reduction below 1 μm has a negligible impact on electrical properties in comparison to alloying elements, which considerably impair the electrical conductivity.

1. Introduction

Pure aluminium is well known for its good correlation between mechanical strength and density as well as an excellent corrosion resistance. It is widely used in automotive, aerospace and construction industries. Nonetheless, its mechanical performance in comparison to other structural materials, such as steel, is poor. Many different methods are used to improve the mechanical strength of aluminium with Severe Plastic Deformation (SPD) processes being one of the most popular and known as an effective way of production ultrafine grained (UFG) materials [1]. In the case of Al and its alloys, the achieved grain size is at the level of 1 μm to 100 nm [2]. Such materials feature extremely high strength due to grain boundary strengthening as described quantitatively by the Hall–Petch relationship [3–5]. Nowadays, the most popular SPD techniques include Equal Channel Angular Pressing (ECAP) [6,7] and High-Pressure Torsion (HPT) [8]. Also, Hydrostatic Extrusion (HE) was proved to be an efficient method of grain size refinement [9].

Pure aluminium exhibits additionally one of the highest electrical conductivity (~62% IACS, International Annealed Copper Standard), which is used in many applications e.g. as an eminent conductor or heat dissipation materials for

---

[*] *Corresponding author*. +48 222348740.
E-mail address: marta.lipinska@inmat.pw.edu.pl (M. Lipińska).

http://dx.doi.org/10.1016/j.acme.2016.04.013

Table 1 – Chemical composition of AA 1050 and AA 5483 (wt.%).

Element	Al	Mg	Mn	Si	Fe	Cu	Zn	Zr	Ti
AA 1050	Balanced	max. 0.05	max. 0.05	max. 0.25	max. 0.40	max. 0.05	max. 0.07	–	–
AA 5483	Balanced	4.64	0.91	0.12	0.12	0.003	0.007	0.095	0.009

transmission line. According to widely known Matthiessen's rule (Eq. (1)), the electrical resistivity (ρ), the inverse of electrical conductivity, depends on several microstructural features:

$$\rho = \rho_0 + \Delta\rho_S + \Delta\rho_P + \Delta\rho_V + \Delta\rho_D + \Delta\rho_B \quad (1)$$

where: ρ_0 describes resistivity of pure solvent metal and $\Delta\rho$ corresponds to the rise of electrical resistivity due to atoms in solid solution (S), precipitates (P), vacancies (V), dislocations (D) and grain boundaries (B). Solute atoms dissolved in the matrix have the most detrimental effect on electrical conductivity, as they are the most efficient lattice defects scattering electrons in metallic materials. On the other hand, all these microstructural elements are known as strengthening factors in terms of mechanical properties. A challenge in materials design is to assure both high conductivity and high mechanical strength in aluminium. One of the approaches is to combine severe plastic deformation and post-processing precipitation treatments [10,11]. However, in some Al alloys the precipitation hardening is not efficient [12], e.g. Al–5Mg alloys are generally assumed to be non-age-hardenable.

In this work, the main emphasis was put on the influence of grain boundaries and alloying elements on both mechanical strength and electrical conductivity of single phase aluminium and its alloy. The specific aim of this work is to determine the influence of the alloying elements and grain refinement by SPD processing on electrical conductivity. In the present study different SPD operations were applied to commercially pure aluminium and aluminium alloy 5483, including hydrostatic extrusion, equal channel angular processing and the combination of both. After plastic deformation the electrical conductivity was measured, likewise mechanical properties (microhardness). Microstructure was investigated in order to reveal microstructural features like grains size.

2. Experimental

The examined materials were aluminium 1050 with purity of 99.50 wt.% and aluminium alloy 5483. The exact chemical compositions are presented in Table 1.

Both materials were supplied in the form of hot extruded 50 mm diameter bars. The as-received materials were processed to produce UFG structure by the following SPD methods:

- HE conducted with a reduction from 50 to 10 mm in diameter in a 4-step process and a total true strain of 3.22;
- ECAP with 90° channel and 0° outer angle, 30 mm in diameter die, using route B_C (i.e. the sample was rotated between passes by 90° in the same direction): for AA 1050 rods, 4 passes were applied, which corresponds to a total true strain of 4.2 while for AA 5483 rods, two passes were applied, which corresponds to a total true strain of 2.1;
- ECAP + HE – 2 passes of ECAP in a 90° die with 0^3 outer angle (route C, i.e. the sample was rotated by 180° between passes) followed by hydrostatic extrusion with a reduction to 10 mm in diameter and a total true strain of 5.42.

The processes of HE and ECAP were carried out at the Institute of High Pressure Physics of the Polish Academy of Sciences. As-received samples served as reference ones.

The microstructures were observed using Focused Ion Beam (FIB) microscope (for samples with coarse grained structure) and JEOL 1200EX transmission electron microscope with an accelerating voltage of 120 kV in the case of samples after SPD processing. The cross-sections were examined in each case. Thin foils were prepared using a wire saw, ground down to 150 μm and electropolished at a voltage of 35 V at a temperature of 278 K. Grain size was determined by calculating the equivalent diameter (d_2), defined as the diameter of a circle with equal area as the investigated grain [13]. Apart from equivalent diameter, the grain size diversity was quantified in terms of the equivalent diameter coefficient of variation (CV(d_2)). This parameter is defined as the ratio of the standard deviation to the mean value.

The electrical conductivity was measured at room temperature using eddy current method on SIMGASCOPE SMP10 device according to DIN EN 2004-1 and ASTM E 1004 standards. The surface of each specimen was mechanically polished in order to remove any artefacts prior to measurements. The electrical conductivity was expressed as a relative value of the International Annealed Copper Standard (%IACS).

To measure the mechanical properties of investigated materials, microhardness was conducted using Vicker's method under a load of 100 grams (Hv0.1) for 15 s. For each sample ten measurements were taken and average values are presented.

3. Results and discussion

3.1. *Microstructure*

The microstructures of as received AA 1050 and AA 5483 are presented in Fig. 1. For both materials the microstructure consists of micron size grains with well defined boundaries. In AA 1050 grains are more equiaxial, while for AA 5483 grains feature more elongated shape. The quantitative data regarding the microstructures are summarized in Table 2. The average value of grain size equals approximately to 15 and 4.5 μm for AA 1050 and AA 5483, respectively. The differences in the grain size result from alloying elements, which are known to inhibit the grain growth. Coefficient of variation quantifies the